PB-240 763

PERE MARQUETTE LAKE, MASON COUNTY, MICHIGAN

Pacific Northwest Environmental Research Laboratory

Prepared for:

National Environmental Research Center
Michigan Department of Natural Resources
Michigan National Guard

February 1975

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16. ABSTRACT
Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivided according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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REPORT

ON

PERE MARQUETTE LAKE

MASON COUNTY

MICHIGAN

EPA REGION V

WORKING PAPER No. 205

WITH THE COOPERATION OF THE

MICHIGAN DEPARTMENT OF NATURAL RESOURCES

AND THE

MICHIGAN NATIONAL GUARD

FEBRUARY, 1975

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FOREWORD

The National Eutrophication Survey was initiated in 1972 in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water quality criteria for the Nation's fresh water lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Michigan Department of Natural Resources for professional involvement and to the Michigan National Guard for conducting the tributary sampling phase of the Survey.

A. Gene Gazlay, former Director, and David H. Jenkins, Acting Director, Michigan Department of Natural Resources; and Carlos Fetterolf, Chief Environmental Scientist, and Dennis Tierney, Aquatic Biologist, Bureau of Water Management, Department of Natural Resources, provided invaluable lake documentation and counsel during the course of the Survey. John Vogt, Chief of the Bureau of Environmental Health, Michigan Department of Public Health, and his staff were most helpful in identfying point sources and soliciting municipal participation in the Survey.

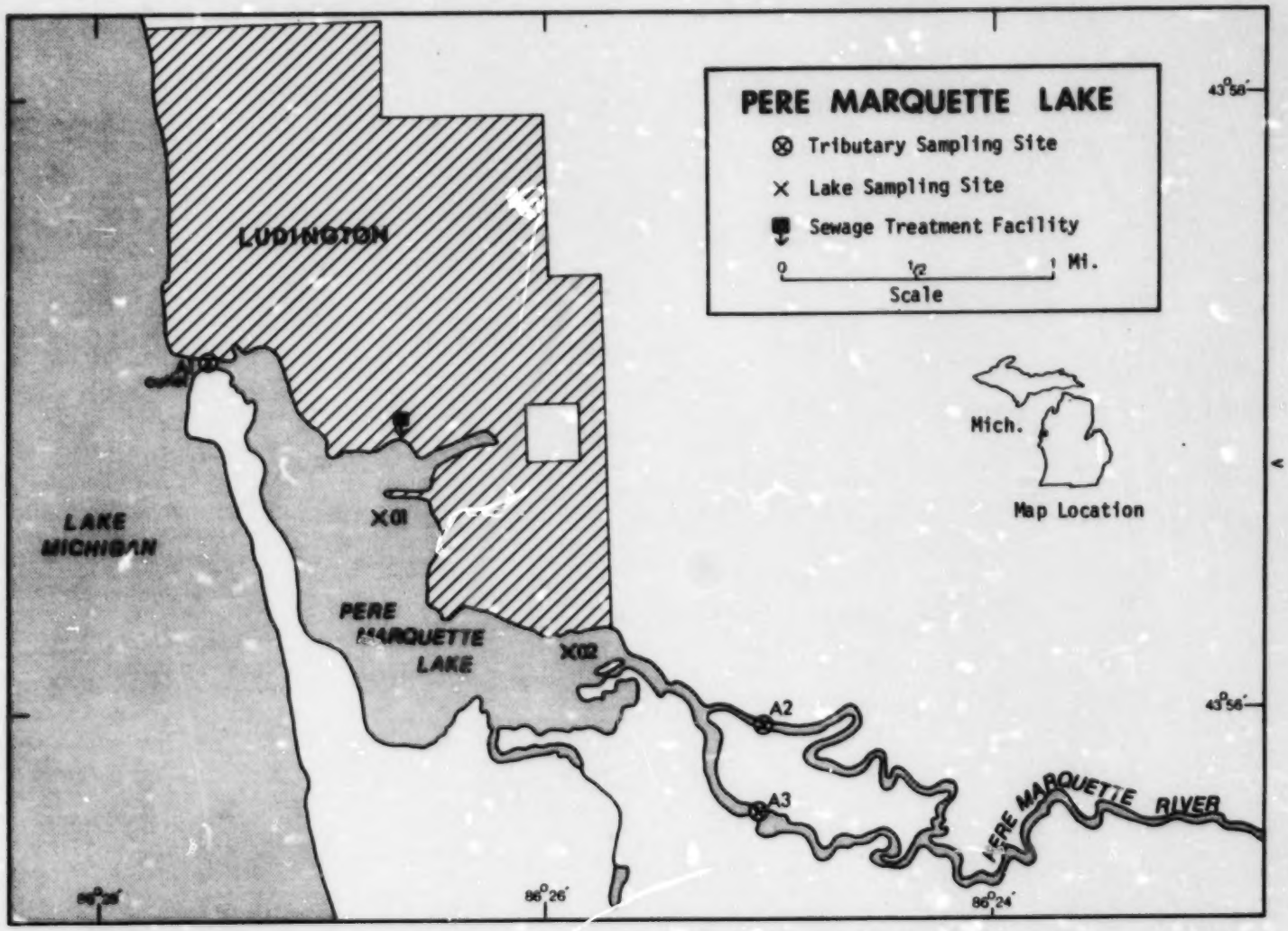
Major General Clarence A. Schnipke (Retired), then the Adjutant General of Michigan, and Project Officer Colonel Albert W. Lesky, who directed the volunteer efforts of the Michigan National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

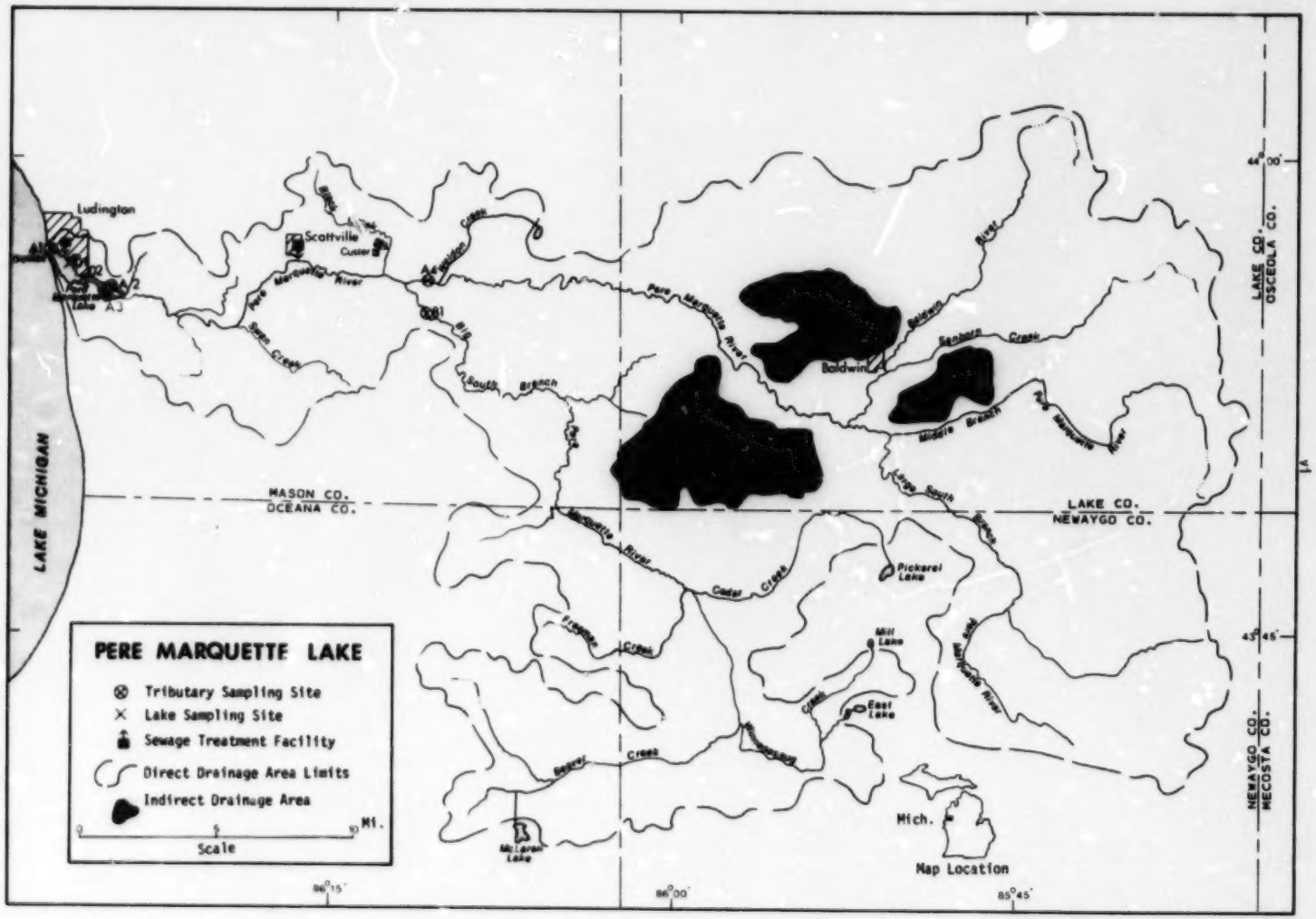
NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF MICHIGAN

LAKE NAME	COUNTY
Allegan Res.	Allegan
Barton	Kalamazoo
Belleville	Wayne
Betsie	Benzie
Brighton	Livingston
Caro Res.	Tuscola
Charlevoix	Charlevoix
Chemung	Livingston
Constantine Res.	St. Joseph
Crystal	Montcalm
Deer	Marquette
Ford	Washtenaw
Fremont	Newago
Higgins	Roscommon
Holloway Res.	Genesee, Lapeer
Houghton	Roscommon
Jordon	Ionia, Barry
Kent	Oakland
Long	St. Joseph
Macatawa	Ottawa
Manistee	Manistee
Mona	Muskegon
Muskegon	Muskegon
Pentwater	Oceana
Pere Marquette	Mason
Portage	Houghton
Randall	Branch
Rogers Pond	Mecosta
Ross	Gladwin
St. Louis Res.	Gratiot
Sanford	Midland
Strawberry	Livingston
Thompson	Livingston
Thornapple	Barry
Union	Branch
White	Muskegon


PERE MARQUETTE LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
0
1/2
1 Mi.
Scale
LUDINGTON
LAKE MICHIGAN
X01
PERE MARQUETTE LAKE
X02
A1
A2
A3
PERE MARQUETTE RIVER
Mich.
Map Location
43°58'
43°56'
86°28'
86°26'
86°24'


PERE MARQUETTE LAKE
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
Direct Drainage Area Limits
Indirect Drainage Area
Scale
Mi.
LAKE MICHIGAN
Ludington
Scottville
Custer
Pere Marquette River
Sweetwater Creek
Big South Branch
Baldwin
Baldwin River
Sauble Creek
Middle Branch
Pere Marquette River
Little South Branch
MASON CO.
OCEANA CO.
LAKE CO.
NEWAYGO CO.
LAKE CO.
OSCEOLA CO.
NEWAYGO CO.
MECOSTA CO.
Marquette River
Cedar Creek
Pickerel Lake
Mill Lake
East Lake
Marquette River
Bailey Creek
McLaren Lake
Mich.
Map Location
86°15'
86°00'
85°45'
43°45'

PERE MARQUETTE LAKE

STORET NO. 2698

I. CONCLUSIONS

A. Trophic Condition:

Survey data show that Pere Marquette Lake is eutrophic. Of the 35 Michigan lakes sampled in November when essentially all were well-mixed, 12 had less mean total phosphorus, 16 had less mean dissolved phosphorus, and nine had less mean inorganic nitrogen; of all 41 lakes sampled, 21 had greater mean Secchi disc transparency, and 19 had less mean chlorophyll a*.

Depression of dissolved oxygen at about 20 feet in depth occurred at station 1 in June and September and at station 2 in September.

B. Rate-Limiting Nutrient:

Algal assay results show that Pere Marquette Lake was phosphorus limited at the time the sample was collected (09/18/72).

The lake data indicate phosphorus limitation in November as well but marginal nitrogen limitation in June.

C. Nutrient Controllability:

1. Point sources--During the sampling year, Pere Marquette Lake received a total phosphorus load at a rate about five times the rate proposed by Vollenweider (in press) as "dangerous";

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* See Appendix A.

i.e., a eutrophic rate (see page 14). However, if the mean depth of Pere Marquette Lake is 14 feet, the mean hydraulic retention time of the lake would be less than six days, so it is probable that Vollenweider's model is not applicable.

It is calculated that the communities of Ludington, Scottville, and Custer contributed 36% of the total phosphorus load to the lake during the sampling year. Removal of 85% of the phosphorus at these three point sources would reduce the loading rate from the existing 15.6 $g/m^2/yr$ to 10.9 $g/m^2/yr$. This reduction should result in persistent phosphorus limitation in the lake (see page 9) and reduce the incidence and severity of nuisance algal blooms, as well as provide additional protection for Lake Michigan.

2. Non-point sources--The mean non-point phosphorus export of 64 pounds per mi^2 for the Pere Marquette River during the sampling year appears to have been somewhat high as compared to the exports of the nearby Manistee River (51 lbs) and Little Manistee River (28 lbs)*. This, together with the export N/P ratio of 23/1 (see page 13), suggests an underestimation of the phosphorus loads from Scottville and Custer or cultural practices in the drainage that result in higher than usual phosphorus inputs to the system.

* Working Paper No. 201.

It is noted that the calculated phosphorus contribution of the river by itself would result in a load of over 88 lbs/acre/yr or more than 9 $g/m^2/yr$. It appears that the high drainage area to lake area ratio of 883 to 1 will ensure a relatively high phosphorus loading to Pere Marquette Lake which points to the need to minimize all phosphorus inputs to the lake to the greatest practicable degree.

II. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry†:

1. Surface area: 554 acres.
2. Mean depth: unknown.
3. Maximum depth: 38+ feet.
4. Volume: unknown.

B. Tributary and Outlet:
(See Appendix B for flow data)

1. Tributaries -

Name	Drainage area*	Mean flow*
Pere Marquette River	768.0 mi^2	671.1 cfs
Minor tributaries & immediate drainage -	6.1 mi^2	6.1 cfs
Totals	774.1 mi^2	677.2 cfs

2. Outlet -

Pere Marquette River	775.0 mi^{2}**	677.2 cfs

C. Precipitation***:

1. Year of sampling: 28.6 inches.
2. Mean annual: 29.9 inches.

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† Fetterolf, 1973.

* Drainage areas are accurate within ±5%; mean daily flows for 74% of the sampling sites are accurate within ±25% and the remaining sites up to ±40%; and mean monthly flows, normalized mean monthly flows, and mean annual flows are slightly more accurate than mean daily flows.

** Includes area of lake.

***See Working Paper No. 1, "Survey Methods, 1972".

III. LAKE WATER QUALITY SUMMARY

Pere Marquette Lake was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from two stations on the lake and from a number of depths at each station (see map, page v). During each visit, a single depth-integrated (15 feet to surface) sample was composited from the stations for phytoplankton identification and enumeration; and during the second visit, a single five-gallon depth-integrated sample was collected for algal assays. Also each time, a depth-integrated sample was collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were 38 feet at station 1 and 22 feet at station 2.

The results obtained are presented in full in Appendix C and the data for the fall sampling period, when the lake essentially was well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix C.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (11/13/72)		
Temperature (Cent.)	6.3	6.8	7.0	7.0
Dissolved oxygen (mg/l)	8.2	8.7	8.8	9.4
Conductivity (μmhos)	400	420	425	430
pH (units)	8.0	8.0	8.0	8.1
Alkalinity (mg/l)	125	133	132	142
Total P (mg/l)	0.027	0.032	0.034	0.037
Dissolved P (mg/l)	0.019	0.024	0.026	0.027
NO_2 + NO_3 (mg/l)	0.170	0.172	0.170	0.180
Ammonia (mg/l)	0.120	0.174	0.200	0.230
		ALL VALUES		
Secchi disc (inches)	36	51	49	72

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Number per ml
06/17/72	1. Oocystis	2,224
	2. Cyclotella	1,302
	3. Achnanthes	344
	4. Cocconeis	108
	5. Melosira	90
	Other genera	200
	Total	4,268
09/18/72	1. Melosira	1,040
	2. Cyclotella	154
	3. Flagellates	154
	4. Rhaphidiopsis	90
	5. Lyngbya	81
	Other genera	588
	Total	2,107
11/13/72	1. Chroococcus	1,039
	2. Flagellates	964
	3. Anabaena	301
	4. Achnanthes	286
	5. Fragilaria	286
	Other genera	1,281
	Total	4,157

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
06/17/72	01	20.3
	02	20.4
09/18/72	01	12.1
	02	16.5
11/13/72	01	0.7
	02	1.0

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)	N/P Ratio
Control	0.012	0.180	4.3	15/1
0.010 P	0.022	0.180	5.4	8/1
0.020 P	0.032	0.180	5.8	
0.050 P	0.062	0.180	5.8	
0.050 P + 5.0 N	0.062	5.180	27.8	
0.050 P + 10.0 N	0.062	10.180	27.6	
10.0 N	0.012	10.180	4.4	

2. Discussion -

The control yield of the assay alga, Selenastrum capricornutum, indicates that the potential primary productivity of Pere Marquette Lake was moderately high at the time the assay sample was collected (09/18/72).

The N/P ratio of the control sample, and the lack of response to the nitrogen only spike, show that the lake was phosphorus limited at the time of sampling. However,

the first phosphorus spike of only 0.010 mg/l nearly doubled the orthophosphorus concentration in the sample; nitrogen then became limiting, so there was only a slight yield response to phosphorus (equivalent to the addition of about 0.003 mg/l at which level nitrogen became limiting, and the additional 0.007 mg/l of ortho-P did not increase the yield).

The lake data indicate phosphorus limitation in November as well (N/P ratio = 14/1) but marginal nitrogen limitation in June (N/P = 12/1).

IV. NUTRIENT LOADINGS
(See Appendix D for data)

For the determination of nutrient loadings, the Michigan National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page vi), except for high runoff months when two samples were collected. Sampling was begun in October, 1972, and was completed in September, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the Michigan District Office of the U.S. Geological Survey for the tributary sites nearest the lake.

In this report, nutrient loads for sampled tributaries were determined by using a modification of a U.S. Geological Survey computer program for calculating stream loadings*. Nutrient loadings for "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S.) were estimated by using the means of the nutrient concentrations in the Big South Branch, Pere Marquette River at station B-1 and the mean ZZ flow.

The operator of the Ludington wastewater treatment plant provided monthly effluent samples and corresponding flow data. However, the communities of Custer and Scottville did not participate in the Survey, and nutrient loads were estimated at 2.5 lbs P and 7.5 lbs N/capita/year and were assumed to have reached the lake during the sampling year.

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* See Working Paper No. 1.

In the following loading tables, the loads attributed to the Pere Marquette River are those measured at A-2 and A-3 minus the point source loads.

A. Waste Sources:

1. Known municipal† -

Name	Pop. Served*	Treatment	Mean Flow (mgd)	Receiving Water
Ludington	9,021	primary	2.405	Pere Marquette Lake
Scottville	1,202	stab. ponds	0.114**	Pere Marquette River
Custer	320	stab. ponds	0.036**	Black Creek

2. Known industrial - None

† Wetzel, 1973.
* 1970 Census.
** Estimated at 100 gal/capita/day.

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Tributaries (non-point load) -		
Pere Marquette River	49,000	63.3
b. Minor tributaries & immediate drainage (non-point load) -	410	0.5
c. Known municipal STP's -		
Ludington	24,050	31.1
Scottville	3,000	3.9
Custer	800	1.1
d. Septic tanks - Unknown	-	-
e. Known industrial - None	-	-
f. Direct precipitation* -	90	0.1
Total	77,350	100.0

2. Outputs -

Lake outlet - Pere Marquette River	71,140

3. Net annual P accumulation - 6,210 pounds

* See Working Paper No. 1.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/yr	% of total
a. Tributaries (non-point load) -		
Pere Marquette River	1,137,500	89.8
b. Minor tributaries & immediate drainage (non-point load) -	12,310	1.0
c. Known municipal STP's -		
Ludington	99,940	7.9
Scottville	9,020	0.7
Custer	2,400	0.2
d. Septic tanks - Unknown	-	-
e. Known industrial - None	-	-
f. Direct precipitation* -	5,340	0.4
Total	1,266,510	100.0

2. Outputs -

Lake outlet - Pere Marquette River	1,564,120

3. Net annual N loss - 297,610 pounds

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	lbs $P/mi^2/yr$	lbs $N/mi^2/yr$	N/P Ratio
Pere Marquette River	64	1,481	23/1

* See Working Paper No. 1.

E. Yearly Loading Rates:

In the following table, the existing phosphorus loading rates are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving water would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

Note that Vollenweider's model may not be applicable to water bodies with very short hydraulic retention times.

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	139.6	11.2	2,286.1	loss*
grams/m^2/yr	15.65	1.26	256.2	-

Vollenweider loading rates for phosphorus ($g/m^2/yr$) based on surface area and mean outflow of Pere Marquette Lake:

"Dangerous" (eutrophic rate)	3.10
"Permissible" (oligotrophic rate)	1.55

* The apparent loss of nitrogen during the sampling year may have been due to nitrogen fixation in the lake, solubilization of previously sedimented nitrogen, recharge with nitrogen-rich ground water, underestimation of loads from known point sources, or unknown point sources discharging directly to the lake. Whatever the cause, a similar loss has been observed at Shagawa Lake, Minnesota, which has been intensively studied by EPA's National Eutrophication and Lake Restoration Branch.

V. LITERATURE REVIEWED

Fetterolf, Carlos, 1973. Personal communication (lake morphometry). MI Dept. of Nat. Resources, Lansing.

Wetzel, Michael, 1973. Treatment plant questionnaires (Ludington, Custer, and Scottville waste treatment facilities). MI Dept. of Publ. Health, Lansing.

Vollenweider, Richard A. (in press). Input-output models. Schweiz. Z. Hydrol.

VI. APPENDICES

APPENDIX A

LAKE RANKINGS

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES MEAN TOTAL P	FALL VALUES MEAN DISS P	FALL VALUES MEAN INORG N	ALL VALUES SEC-MEAN SEC	ALL VALUES MEAN CHLORA	ALL VALUES 1%-MIN DO
2640	HOLLOWAY RESERVOIR	0.062	0.043	1.461	439.375	10.678	9.200
2641	CARO RESERVOIR	0.117	0.022	3.835	473.000	11.967	9.500
2642	BOARDMAN HYDRO POND	0.006	0.005	0.358	363.500	1.267	6.600
2643	ALLEGAN LAKE	0.123	0.057	1.168	470.222	20.311	12.600
2646	BURTON LAKE	0.121	0.006	1.489	456.167	27.800	14.650
2649	BELLEVILLE LAKE	0.118	0.048	1.428	465.250	28.262	8.200
2650	BETSIE LAKE	0.025	0.008	0.273	441.667	4.567	7.400
2653	BRIGHTON LAKE	0.109	0.073	1.015	456.000	44.233	7.500
2657	LAKE CHARLEVOIX	0.007	0.006	0.230	351.250	3.000	9.240
2658	LAKE CHEMUNG	0.044	0.014	0.132	404.333	13.483	14.000
2661	CONSTANTINE RESERVOIR	0.027	0.008	0.910	456.167	39.317	7.500
2669	FORD LAKE	0.105	0.058	1.536	456.167	14.733	14.000
2671	FREMONT LAKE	0.372	0.342	1.406	441.667	28.500	14.000
2680	JORDAN LAKE	0.188	0.144	1.998	427.667	20.517	14.900
2683	KENT LAKE	0.040	0.015	0.417	455.000	33.944	13.000
2688	LAKE MACATAWA	0.197	0.120	2.358	477.000	25.000	12.200
2689	MANISTEE LAKE	0.018	0.010	0.384	451.333	6.317	11.300
2699	MUSKEGON LAKE	0.087	0.043	0.469	436.444	9.511	14.000
2705	PENTWATER LAKE	0.027	0.017	0.496	430.667	16.083	14.000
2711	RANDALL LAKE	0.246	0.163	0.810	457.333	27.217	8.020
2712	ROGERS POND	0.026	0.015	0.183	435.500	8.133	9.600
2713	RUSS RESERVOIR	0.034	0.021	0.460	465.333	10.383	8.200
2714	SANFORD LAKE	0.016	0.008	0.307	458.750	13.791	8.300
2723	THORNAPPLE LAKE	0.042	0.032	1.737	442.833	14.650	10.800
2725	UNION LAKE	0.083	0.064	1.252	455.500	15.667	8.200
2728	WHITE LAKE	0.027	0.019	0.367	417.778	9.211	13.400
2731	MONA LAKE	0.387	0.241	0.963	451.667	27.783	14.100
2732	LONG LAKE	0.163	0.148	0.740	418.400	10.067	13.600

LAKE DATA TO BE USED IN RANKINGS

LAKE CODE	LAKE NAME	FALL VALUES MEAN TOTAL P	FALL VALUES MEAN DISS P	FALL VALUES MEAN INORG N	ALL VALUES 500- MEAN SEC	ALL VALUES MEAN CHLORA	ALL VALUES 15- MIN DO
2693	ST LOUIS RESERVOIR	0.134	0.093	1.227	462.667	5.583	8.420
2694	CRYSTAL LAKE	0.009	0.006	0.164	380.000	2.986	13.000
2695	HIGGINS LAKE	0.007	0.005	0.058	268.500	1.043	9.400
2696	HOUGHTON LAKE	0.018	0.008	0.136	420.833	9.217	8.200
2697	THOMPSON LAKE	0.043	0.029	0.436	407.889	11.967	14.800
2698	PERE MARQUETTE LAKE	0.032	0.024	0.346	448.667	11.833	8.600
2699	STRAWBERRY LAKE	0.069	0.050	0.567	419.800	11.117	13.600

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	ALL VALUES: MEAN TOTAL P	ALL VALUES: MEAN DISS P	ALL VALUES: MEAN INORG N	ALL VALUES: SDD-MEAN SEC	ALL VALUES: MEAN CHLOPA	ALL VALUES: 15-MIN DO	INDEX NO
26A0	HOLLOWAY RESERVOIR	46 (16)	43 (15)	17 (6)	57 (20)	60 (21)	63 (22)	286
26A1	CARO RESERVOIR	29 (10)	54 (19)	0 (0)	3 (1)	49 (17)	54 (19)	189
26A2	BOARDMAN HYDRO POND	97 (34)	97 (34)	69 (24)	91 (32)	94 (33)	97 (34)	565
2603	ALLEGAN LAKE	20 (7)	31 (11)	31 (11)	6 (2)	29 (10)	40 (14)	157
2606	BARTON LAKE	23 (8)	20 (7)	14 (5)	29 (9)	14 (5)	3 (1)	103
2609	BELLEVILLE LAKE	26 (9)	37 (13)	20 (7)	11 (4)	11 (4)	79 (26)	184
2610	BETSIE LAKE	77 (27)	77 (27)	80 (28)	17 (6)	86 (30)	94 (33)	431
2613	BRIGHTON LAKE	31 (11)	23 (8)	34 (12)	34 (12)	0 (0)	90 (31)	212
2617	LAKE CHARLEVOIX	91 (32)	91 (32)	83 (29)	94 (33)	89 (31)	60 (21)	508
2618	LAKE CHEMUNG	49 (17)	71 (25)	94 (33)	86 (30)	46 (16)	11 (2)	357
2621	CONSTANTINE RESERVOIR	71 (25)	83 (29)	40 (14)	29 (9)	3 (1)	90 (31)	316
2629	FORD LAKE	34 (12)	29 (10)	11 (4)	29 (9)	37 (13)	23 (8)	163
2631	FREMONT LAKE	0 (0)	0 (0)	23 (8)	54 (19)	9 (3)	11 (2)	97
2640	JORDAN LAKE	11 (4)	11 (4)	6 (2)	69 (24)	26 (9)	0 (0)	123
2643	KENT LAKE	57 (20)	69 (24)	63 (22)	40 (14)	6 (2)	36 (12)	271
2648	LAKE MACATAWA	9 (3)	14 (5)	3 (1)	0 (0)	23 (8)	43 (15)	92
2649	MANISTEE LAKE	80 (28)	74 (26)	77 (27)	46 (16)	80 (28)	46 (16)	403
2659	MUSKEGON LAKE	37 (13)	40 (14)	54 (19)	60 (21)	69 (24)	11 (2)	271
2665	PENTWATER LAKE	69 (24)	63 (22)	51 (18)	66 (23)	31 (11)	11 (2)	291
2671	RANDALL LAKE	6 (2)	6 (2)	43 (15)	23 (8)	20 (7)	86 (30)	184
2672	ROGERS POND	74 (26)	66 (23)	86 (30)	63 (22)	77 (27)	51 (18)	417
2673	ROSS RESERVOIR	60 (21)	57 (20)	57 (20)	9 (3)	63 (22)	79 (26)	325
2674	SANFORD LAKE	86 (30)	80 (28)	74 (26)	20 (7)	43 (15)	71 (25)	374
2683	THORNAPPLE LAKE	54 (19)	46 (16)	9 (3)	51 (18)	40 (14)	49 (17)	249
2685	UNION LAKE	40 (14)	26 (9)	26 (9)	37 (13)	34 (12)	79 (26)	242
2688	WHITE LAKE	66 (23)	60 (21)	66 (23)	80 (28)	74 (26)	31 (11)	377
2691	MONA LAKE	3 (1)	3 (1)	37 (13)	43 (15)	17 (6)	20 (7)	123
2692	LONG LAKE	14 (5)	9 (3)	46 (16)	77 (27)	66 (23)	27 (9)	239

PERCENT OF LAKES WITH HIGHER VALUES (NUMBER OF LAKES WITH HIGHER VALUES)

LAKE CODE	LAKE NAME	FALL VALUES: MEAN TOTAL P	FALL VALUES: MEAN DISS P	FALL VALUES: MEAN INORG N	ALL VALUES: 500- MEAN SEC	ALL VALUES: MEAN CHLORA	ALL VALUES: 1S- MIN DO	INDEX NO
2693	ST LOUIS RESERVOIR	17 (6)	17 (6)	29 (10)	14 (5)	83 (29)	69 (24)	229
2694	CRYSTAL LAKE	89 (31)	89 (31)	89 (31)	89 (31)	91 (32)	36 (12)	483
2695	HIGGINS LAKE	94 (33)	94 (33)	97 (34)	97 (34)	97 (34)	57 (20)	536
2696	HOUGHTON LAKE	83 (29)	86 (30)	91 (32)	71 (25)	71 (25)	79 (26)	481
2697	THOMPSON LAKE	51 (18)	49 (17)	60 (21)	83 (29)	51 (18)	11 (2)	305
2698	PERE MARQUETTE LAKE	63 (22)	51 (18)	71 (25)	49 (17)	54 (19)	66 (23)	354
2699	STRAWBERRY LAKE	43 (15)	34 (12)	49 (17)	74 (26)	57 (20)	27 (9)	284

APPENDIX B

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2651 PERE MARQUETTE LAKE

TOTAL DRAINAGE AREA OF LAKE(SQ MI) 775.00

TRIBUTARY	SUB-DRAINAGE AREA(SQ MI)	NORMALIZED FLOWS(CFS) JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
2651A1	775.00	671.00	663.00	904.00	1032.00	800.00	665.00	518.00	472.00	502.00	559.00	662.00	682.00	677.21
2651A2	384.00	200.00	197.00	268.00	307.00	238.00	198.00	154.00	140.00	149.00	166.00	197.00	203.00	201.33
2651A3	384.00	466.00	460.00	626.00	716.00	555.00	461.00	359.00	328.00	349.00	388.00	459.00	473.00	469.79
2651ZZ	7.00	6.00	6.00	9.00	9.00	7.00	6.00	5.00	4.00	4.00	5.00	6.00	6.00	6.08

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 775.00
SUM OF SUB-DRAINAGE AREAS = 775.00
TOTAL FLOW IN = 8130.00
TOTAL FLOW OUT = 8130.00

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
2651A1	10	72	589.00	28	871.00				
	11	72	644.00	30	617.00				
	12	72	658.00						
	1	73	1120.00	7	926.00				
	2	73	831.00	4	1070.00				
	3	73	1190.00	4	1000.00	28	867.00		
	4	73	937.00	29	801.00				
	5	73	946.00	13	1144.00				
	6	73	729.00	9	764.00	22	638.00		
	7	73	550.00	8	564.00	16	528.00		
	8	73	472.00						
	9	73	431.00	8	431.00	9	425.00	30	433.00
2651A2	10	72	253.00	28	374.00				
	11	72	277.00	30	265.00				
	12	72	283.00						
	1	73	482.00	7	398.00				
	2	73	357.00	4	460.00				
	3	73	512.00	4	430.00	28	373.00		
	4	73	403.00	29	344.00				
	5	73	407.00	13	492.00				
	6	73	313.00	9	329.00	22	274.00		
	7	73	236.00	8	243.00	16	227.00		
	8	73	203.00						
	9	73	185.00	8	185.00	9	183.00	30	186.00

TRIBUTARY FLOW INFORMATION FOR MICHIGAN 2/3/75

LAKE CODE 2651 PERE MARQUETTE LAKE

MEAN MONTHLY FLOWS AND DAILY FLOWS(CFS)

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
265183	10	72	330.00	28	458.00				
	11	72	361.00	30	346.00				
	12	72	368.00						
	1	73	627.00	7	519.00				
	2	73	465.00	4	599.00				
	3	73	666.00	4	560.00	28	486.00		
	4	73	525.00	29	449.00				
	5	73	530.00	13	641.00				
	6	73	408.00	9	428.00	22	357.00		
	7	73	308.00	6	316.00	16	296.00		
	8	73	264.00						
	9	73	241.00	6	241.00	9	238.00	30	242.00
265122	10	72	6.00						
	11	72	6.00						
	12	72	7.00						
	1	73	11.00						
	2	73	9.00						
	3	73	12.00						
	4	73	9.00						
	5	73	9.00						
	6	73	8.00						
	7	73	5.00						
	8	73	5.00						
	9	73	5.00						

APPENDIX C

PHYSICAL and CHEMICAL DATA

STORET RETRIEVAL DATE 75/02/04

265101
43 56 00.0 086 26 00.0
PERE MARQUETTE LAKE
26105 MICHIGAN

11EPALES 2111202
5 0016 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/17	17 52	0000	18.2	9.4	36	350	8.15	147	0.080	0.080	0.030	0.018
	17 52	0015	17.7	9.0		360	8.10	145	0.080	0.080	0.055	0.016
72/09/18	12 30	0000			00	560	8.50	143	0.100	0.110	0.019	0.016
	12 30	0004	19.4	8.3		535	8.50	143	0.090	0.100	0.025	0.014
	12 30	0015	18.6	7.5		468	8.40	144	0.100	0.170	0.025	0.017
	12 30	0022	18.8	7.5		650	8.20	143	0.100	0.140	0.027	0.015
72/11/13	11 40	0000			43	420	8.16	125	0.170	0.120	0.028	0.020
	11 40	0004	6.3	9.4		400	8.00	126	0.170	0.120	0.028	0.019
	11 40	0016	6.4	8.8		400	8.00	127	0.180	0.120	0.027	0.020

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/17	17 52	0000	20.4J
72/09/18	12 30	0000	16.5J
72/11/13	11 40	0000	1.0J

J VALUE KNOWN TO BE IN ERROR

STORET RETRIEVAL DATE 75/02/04

265101
43 56 30.0 086 27 00.0
PERE MARQUETTE LAKE
26105 MICHIGAN

11EPALES 2111202
5 0030 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/17	17	24 0000	16.6	9.4	49	360	8.15	144	0.100	0.080	0.062	0.014
	17	24 0015	16.1	7.4		370	8.04	145	0.100	0.100	0.030	0.013
	17	24 0030	15.5	7.6		375	7.88	144	0.120	0.170	0.092	0.026
72/09/18	12	00 0000			72	445	8.48	143	0.090	0.160	0.023	0.018
	12	00 0004	19.0	8.0		440	8.45	142	0.090	0.150	0.034	0.018
	12	00 0015	18.7	7.7		440	8.40	144	0.100	0.170	0.029	0.019
	12	00 0022	18.6	7.1		460	8.35	146	0.100	0.180	0.031	0.019
	12	00 0030	18.5	7.1		460	8.35	144	0.090	0.170	0.028	0.018
	12	00 0038	18.2	6.4		445	8.25	144	0.090	0.220	0.043	0.020
72/11/13	11	20 0000			48	430	8.00	129	0.180	0.200	0.037	0.026
	11	20 0004	7.0	8.2		430	8.00	134	0.170	0.230	0.036	0.027
	11	20 0015	7.0	8.8		425	8.00	142	0.170	0.200	0.035	0.027
	11	20 0025	7.0	8.8		425	8.00	141	0.170	0.200	0.034	0.026
	11	20 0036	7.0	9.4		430	8.00	142	0.170	0.200	0.034	0.026

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/17	17	24 0000	20.30
72/09/18	12	00 0000	12.10
72/11/13	11	20 0000	0.70

J VALUE FROM T[illegible]

APPENDIX D

TRIBUTARY and WASTEWATER TREATMENT PLANT DATA

STORET RETRIEVAL DATE 75/02/04

```
                                                    265141          LS2651A1
                                                43 47 00.0 086 27 30.0
                                                PERE MARQUETTE RIVER
                                                26101    15 LUDINGTON
                                                U/PERE MARQUETTE LAKE
                                                MAIN SAMPLE SW EDGE OF LUDINGTON
                                                11EPALES                2111204
                                                4                       0000 FEET  DEPTH
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DATE FROM / TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/24			0.153	1.450	0.189	0.021	0.034
72/11/30	17 00		0.195	0.480	0.154	0.032	0.055
73/01/07	07 31		0.360	1.400	0.200	0.030	0.060
73/02/04	08 05		0.231	1.200	0.150	0.017	0.030
73/03/04	08 47		0.231	0.440	0.140	0.014	0.035
73/03/24	17 15		0.070	0.400	0.061	0.013	0.025
73/04/29	09 05		0.100	2.400	0.176	0.027	0.050
73/05/13	10 10		0.120	0.820	0.210	0.038	0.080
73/06/04	11 00		0.105	0.520	0.100	0.022	0.050
73/06/22	08 35		0.140	1.700	0.440	0.029	0.070
73/07/08	09 15		0.125	0.540	0.105	0.010	0.035
73/07/16	18 10		0.110	0.480	0.120	0.020	0.050
73/09/09	08 30		0.060	0.340	0.039	0.014	0.070
73/09/30	09 00		0.095	0.440	0.088	0.011	0.045

STORET RETRIEVAL DATE 75/02/04

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 2651A2          LS2651A2
43 46 00.0 086 25 00.0
PERE MARQUETTE RIVER
26       15 LUDINGTON
1/PERE MARQUETTE LAKE
US31 BRDG S JCT US 31 WITH US 10
11EPALES                  2111204
4                         0000 FEET  DEPTH
```

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/26	17 30		0.093	1.400	0.100	0.014	0.044
72/11/30	16 20		0.178	1.800	0.064	0.010	0.024
73/01/07	08 44		0.220	1.200	0.066	0.017	0.061
73/02/04	08 45		0.290	0.390	0.034	0.012	0.030
73/03/04	08 10		0.250	0.540	0.040	0.010	0.030
73/03/28	16 15		0.060	0.310	0.012	0.015	0.020
73/04/29	09 10		0.071	1.470	0.078	0.017	0.035
73/05/13	10 20		0.040	0.720	0.054	0.016	0.050
73/06/09	10 45		0.075	0.440	0.044	0.032	0.065
73/06/22	08 45		0.063	0.540	0.057	0.035	0.065
73/07/04	09 30		0.058	0.440	0.037	0.019	0.055
73/07/16	16 55		0.066	0.400	0.050	0.020	0.050
73/09/09	08 45		0.220	0.540	0.198	0.016	0.055
73/09/30	09 15		0.061	0.365	0.046	0.012	0.030

STORET RETRIEVAL DATE 75/02/04

265143 LS265143
43 56 00.0 086 25 00.0
PERE MARQUETTE RIVER
26 15 LUDINGTON
1/PERE MARQUETTE LAKE
US31 BRDG 2 MI S JCT US 31 WITH US 10
11EMALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	17 20		0.104	0.750	0.054	0.010	0.037
72/11/30	16 00		0.168	1.380	0.066	0.010	0.021
73/01/07	08 00		0.220	1.320	0.054	0.009	0.022
73/02/04	08 35		0.273	0.480	0.042	0.012	0.030
73/03/04	07 43		0.370	0.480	0.046	0.014	0.045
73/03/28	16 00		0.075	1.800	0.088	0.010	0.020
73/04/29	09 20		0.087	1.100	0.044	0.021	0.045
73/05/13	10 30		0.050	0.657	0.019	0.018	0.056
73/06/04	10 35		0.097	0.500	0.042	0.027	0.065
73/06/22	08 40		0.126	0.500	0.031	0.026	0.050
73/07/08	14 20		0.115	0.390	0.032	0.015	0.045
73/07/16	16 45		0.087	0.260	0.022	0.016	0.035
73/09/09	08 10		0.044	0.210	0.042	0.030	0.035
73/09/30	09 14		0.091	0.300	0.026	0.011	0.030

STORET RETRIEVAL DATE 75/02/04

2651A4 LS2651A4
43 56 30.0 086 11 00.0
PERE MARQUETTE
26 15 CUSTER
T/PERE MARQUETTE LAKE
ROAD BRDG 1.5 MI E & .75 MIS CUSTER
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	14 55		0.054	0.400	0.050	0.005K	0.014
72/11/30	18 00		0.083	0.460	0.015	0.005K	0.012
73/01/07	10 45		0.130	0.340	0.027	0.008	0.015
73/02/04	09 20		0.168	0.210	0.027	0.008	0.020
73/03/04	10 45		0.160	0.300	0.037	0.008	0.020
73/03/28	18 00		0.078	0.180	0.018	0.009	0.020
73/04/29	08 30		0.035	0.350	0.015	0.009	0.010
73/05/13	10 30		0.029	1.150	0.013	0.005K	0.025
73/06/10	07 45		0.024	0.370	0.012	0.007	0.035
73/06/22	19 00		0.029	0.540	0.024	0.010	0.030
73/07/08	13 00		0.033	0.630	0.029	0.005K	0.020
73/07/16	18 05		0.016	0.150	0.030	0.008	0.020
73/09/04	17 00		0.095	0.270	0.063	0.016	0.025
73/09/30	19 15		0.027	1.050	0.056	0.007	0.020

K VALUE KNOWN TO BE
LESS THAN INDICATED

STORET RETRIEVAL DATE 75/02/04

265181 LS265181
43 46 00.0 086 11 00.0
BIG S BRNCH PERE MARQUETTE RIVER
26 15 CUSTER
1/PERE MARQUETTE LAKE
RD HRUG 1.5 MI S 2 MI E OF CUSTER
11EMALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/10/28	14 14		0.400	0.800	0.073	0.007	0.034
72/11/30	18 30		0.115	2.100	0.075	0.008	0.024
73/01/07	11 09		0.280	1.150	0.075	0.010	0.024
73/02/04	09 45		0.190	0.640	0.083	0.010	0.030
73/03/04	10 30		0.310	1.300	0.189	0.027	0.080
73/03/28	17 45		0.086	0.420	0.016	0.009	0.025
73/04/29	08 00		0.056	1.600	0.069	0.011	0.025
73/05/13	10 05		0.040	0.770	0.025	0.006	0.040
73/06/10	08 00		0.096	0.580	0.016	0.012	0.045
73/06/22	19 40		0.100	0.480	0.014	0.014	0.040
73/07/08	13 30		0.078	0.680	0.031	0.006	0.035
73/07/16	18 50		0.034	1.100	0.042	0.013	0.025
73/09/08	17 45		0.052	0.350	0.040	0.012	0.025
73/09/30	19 50		0.028	0.240	0.168	0.008	0.025

STORET RETRIEVAL DATE 75/02/04

2c5150 P0265150 P0049U0
43 57 30.0 086 26 30.0
LUDINGTON
26 15 LUDINGTON
U/PERE MARQUETTE LAKE
PERE MARQUETTE LAKE
11EPALES 2141204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50050 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/01/29 00 00									
CP(T)-			1.050	9.600	0.049	1.200	3.200	2.850	2.930
73/01/30 24 00									
73/02/20 00 00									
CP(T)-			1.700	11.000	0.500	1.100	2.800	3.000	2.890
73/02/20 24 00									
73/03/21 00 00									
CP(T)-			1.800	11.000	0.640	1.300	2.500	2.920	2.870
73/03/22 24 00									
73/04/26 00 00									
CP(T)-			1.420	11.500	0.163	0.825	2.500	2.100	2.470
73/04/26 24 00									
73/05/25 00 00									
CP(T)-			3.200	10.500	0.470	0.860	2.500	2.450	2.490
73/05/25 24 00									
73/06/23			2.300	11.000	0.060	0.730	2.000	1.800	2.180
73/07/29 00 00									
CP(T)-			1.010	12.000	1.050	1.130	3.000	1.470	1.830
73/07/29 24 00									
73/08/27 00 00									
CP(T)-			1.420	13.000	1.200	1.440	3.800	1.580	2.040
73/08/27 24 00									
73/09/25 00 00									
CP(T)-			1.980	9.200	0.400	1.470	2.700	2.710	2.170
73/09/25 24 00									
73/10/31 00 00									
CP(T)-			0.740	9.400	0.580	1.470	2.700	2.810	1.940
73/10/31 24 00									
73/11/29 00 00									
CP(T)-			3.400	13.000	0.250	1.540	3.500	2.640	2.580
73/11/29 24 00									
73/12/26 00 00									
CP(T)-			0.330	15.300	2.900	0.330	7.800	2.860	2.460
73/12/26 24 00									
74/01/22 00 00									
CP(T)-			3.200	20.500	3.300	0.150	3.150	2.920	2.410
74/01/22 24 00									

STORET RETRIEVAL DATE 75/02/04

265151 PU265151 P001140
43 57 00.0 086 16 30.0
SCOTVILLE
26 15 LUDINGTON
T/PERE MARQUETTE LAKE
PERE MARQUETTE RIVER
11EPALES 2141204
0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/04/18	08 00								
CP(T)-			0.095	11.500	1.160	2.900	3.800		
73/04/18	16 00								